Growth and physiological characteristics
of the weed false johnsongrass (*Sorghum arundinaceum* (Desv.) Stapf)

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ABSTRACT

Sorghum arundinaceum (Desv.) Stapf a weed that belongs to the Poaceae family and is widespread throughout Brazil. Despite the frequent occurrence, infesting cultivated areas, there is little research concerning the biology and physiology of this species. The objective of this research was to evaluate the growth, carbon partitioning and physiological characteristics of the weed *Sorghum arundinaceum* in greenhouse. Plants were collected at regular intervals of seven days, from 22 to 113 days after transplanting (DAT). In each sample, we determined plant height, root volume, leaf area and dry matter, and subsequently we performed the growth analysis. We have determined the dry matter partitioning among organs, the accumulation of dry matter, the specific leaf area, the relative growth rate and leaf weight ratio. At 36, 78 and 113 DAT, the photosynthetic and transpiration rates, stomatal conductance, CO_2 concentration and chlorophyll fluorescence were evaluated. The *Sorghum arundinaceum* reached 1.91 m in height, with slow initial growth and allocated much of the biomass in the roots. The photosynthetic rate and the maximum quantum yield of FSII are similar throughout the growth cycle. At maturity the *Sorghum arundinaceum* presents higher values of transpiration rate, stomatal conductance and non-photochemical quenching coefficient (NPQ).

Key words: growth analysis, gas exchange, chlorophyll a fluorescence.

RESUMO

Crescimento e características fisiológicas
da planta daninha falso-massambará (*Sorghum arundinaceum* (Desv.) Stapf)

Sorghum arundinaceum (Desv.) Stapf é uma planta daninha pertencente à família Poaceae e encontra-se disseminada em todo o território brasileiro. Apesar da ocorrência frequente, infestando áreas cultivadas, são poucas as pesquisas concernentes à biologia e à fisiologia desta espécie. Objetivou-se com esta pesquisa avaliar o crescimento, a partição de fotoassimilados e as características fisiológicas da planta daninha *Sorghum arundinaceum,* em casa de vegetação. As plantas foram coletadas em intervalos regulares de sete dias, a partir de 22 e até 113 dias após o transplantio (DAT). Em cada coleta, determinaram-se altura de plantas, volume de raiz, área foliar e massa seca e, posteriormente, aplicou-se a análise de crescimento, sendo calculada a partição de massa seca entre os órgãos, o acúmulo de massa seca, a área foliar específica, a taxa de crescimento relativo e a razão de peso foliar. Aos 36, 78 e 113 DAT foram avaliadas as taxas fotossintética e transpiratória, a condutância estomática, a relação entre a concentração

interna e externa de CO_2 e a fluorescência da clorofila a. O *Sorghum arundinaceum* apresentou a altura de 1,91 metros, com crescimento inicial lento e alocou grande parte da biomassa nas raízes. A taxa fotossintética e o rendimento quântico máximo do FS II são semelhantes, durante todo o ciclo de crescimento. Na maturação, o *Sorghum arundinaceum* apresenta maiores valores de taxa transpiratória, condutância estomática e coeficiente de dissipação não fotoquímico (NPQ).

Palavras-chaves: análise de crescimento, trocas gasosas, fluorescência da clorofila a.

INTRODUCTION

Weeds interfere with the productivity of agricultural crops, mainly because of competition for water, light and nutrients. For its rusticity, weeds stand out for the speed and utilization efficiency of environmental resources (Myers & Anderson, 2003), ensuring their survival and growth advantages, surpassing cultivated plants. The Poaceae family presents significant number of species that have become invasive in Brazil, especially fodder of African origin, specially *Hyparrhenia rufa* (Ness) Stapf (*H. rufa*), *Urochloa* spp. (brachiaria) and *Panicum maximum* Jacq. (guineagrass). According to Castro *at al.* (2011), the fodder grasses have caused significant damage to major crops in Brazil.

Sorghum arundinaceum (Desv.) Stapf is a weed from the Poaceae family, originally from Africa, that has been widespread in all regions of Brazil, and is an annual or perennial plant, erect, with 1.5-2.5 m tall. Its propagation occurs through seeds, infesting especially annual and perennial crops, vacant lands and roadsides. It is confused with *Sorghum halepense*, L. Peers which is distinguished for being perennial, rhizomatous and smaller (Lorenzi, 2008).

The growth analysis of poaceae weeds of tropical regions has received little research attention, and the estimates of parameters such as leaf area, specific leaf area, leaf weight ratio and growth rates are scarce. These analyzes are the most accurate and affordable method to evaluate the growth and to measure the contribution of different physiological processes for plant behavior (Benincasa, 2003). By photosynthesis, plants absorb the active solar radiation and incorporate atmospheric CO_2 into carbon compounds intended for plant growth. Thus, factors such as the reduction of solar radiation on the leaves decrease the amount of radiation absorbed by the photosynthetic apparatus, which reduces the conversion of light energy into chemical energy, affecting the growth and development of the plants (Aumonde *at al.*, 2013).

For these reasons, the studies related to the growth and development of weeds allow necessary information on the phenology and growth patterns, providing subsi-dies for the understanding of its physiological and morphological responses, in face of environmental factors and their effect on the ecological niche, especially their interference on cultivated plants.

The aim of this study was to evaluate growth, photoassimilate partitioning and the physiological characteristics of the weed *Sorghum arundinaceum* in greenhouse, considering the importance of these studies to the knowledge of the ecology of this species.

MATERIAL AND METHODS

The experiment was conducted in an acclimatized greenhouse, with temperature varying from 18 to 29°C, on the premises of the Ecophysiology Laboratory and Plant Productivity, of the Instituto Federal Goiano, Campus Rio Verde, from August to December 2012. The location of the experiment has the following geographical coordinates: latitude 17° 48' and 67'' S and longitude 50° 54' 18'' W, on average altitude of 758 meters.

The seeds of *S. arundinaceum* were collected in soybean crops of Rio Verde and germinated in plastic boxes (11 x 11 x 3 cm), Gerbox type, sown on two sheets of blotting paper, moistened with distilled water, in an amount equivalent to 2.5 times the weight of the dry substrate in accordance with the Rules for Seed Testing (Brasil, 2009). The boxes were kept in a germinator, with temperature alternating from 19-30°C and photoperiod of eight hours of fluorescent white light during the highest temperature. After germination, when there was protrusion of the primary roots three plants were transplanted, to each ex-perimental unit.

The experimental units consisted in eight-liter pots fulfilled with a mixture of sand: subsoil in a 1:2 proportion. The subsoil physico-chemical characteristics were as follow: pH = 5.5; P = 0.35 mg dm^{-3}; K = 19.6 mg dm^{-3}; Ca = 1.4 cmol$_c$ dm^{-3}; Mg = 0.26 cmol$_c$ dm^{-3}; Al = 0.03 cmol$_c$ dm^{-3}; V% = 53.2%; CEC = 3.31 cmol$_c$ dm^{-3} and granulometry 23, 5, and 72 kg dag^{-1} clay, silt and sand, respectively. Afterwards, 184 g of N, 836 g of P_2O_5, 110 g of K_2O and 64 g of Ca plus Mg were added to the soil at a ratio of two portions of soil to one portion of sand. The pots were watered daily and manually, maintaining the substrate at

field capacity. Fertilization was made with nutrient solution of Hoagland & Arnon (1950) every two weeks.

The experiment was installed in an experimental design of randomized blocks, with 14 treatments (harvest periods) and four replications. The periods corresponded to 22, 29, 36, 43, 50, 57, 64, 71, 78, 85, 92, 99, 106 and 113 days after transplantation (DAT). In each evaluation period, the plants were separated into roots, stems, leaves, panicles and seeds. Root volume was measured using a graduated cylinder; the height of the plants, with a millimeter ruler, measuring the length of the stem to the apex of the plant; and the leaf area through the Sigma Scan software Prov. 5.0, Jandel Scientific. Subsequently, the sampled material was packed in paper bags and dried in an oven with forced ventilation at 70°C for 72 hours until reaching constant mass.

The dry matter of root (RDM), stems (SDM), leaves (LDM), seeds (SDM) and panicles (PDM) were measured (in g per plant) in a digital analytical scale, also being obtained total dry matter (TDM). The specific leaf area (SLA), leaf weight ratio (LWR) and relative growth rate (RGR) were calculated based on leaf area and dry matter of the different plant parts, in the resoective sampling periods, according to Benicasa (2003) and Aguilera *at al.* (2004). Data were statistically analyzed using the F test on the analysis of variance, followed by the application of non-linear regression models, in function of the harvest periods.

The physiological evaluations of gas exchange and chlorophyll *a* fluorescence were performed in three phenological phases: the vegetative growth (36 DAT), the flowering period (78 DAT) and maturation (113 DAT). The gas exchanges related to the photosynthetic rate (A, ì mol m^{-2} s^{-1}), transpiration rate (E, mmol m^{-2} s^{-1}), stomatal conductance (g_s, mol H_2O m^{-2} s^{-1}) and the ratio between the internal and external concentrations of CO_2 (*Ci/Ca*) were determined by an infrared gas analyzer Model LI-6400XTR (Licor®, Nebraska, USA). Measurements were performed between 8h30 min and 10h30 min in a greenhouse, using constant (1000 µmol photons m^{-2} s^{-1}) photosynthetically active radiation (PAR), atmospheric concentration of CO_2 (Ca) (~400 µmol mol^{-1}), leaf chamber temperature (25-35°C) and leaf temperature (30-35°C).

Fluorescence measurements of chlorophyll *a* were evaluated using a portable modulated fluorometer, model MINI-PAM (Walz, Effeltrich, Germany), equipped with a special gripper for leaf support, model 2030-B (Rascher *at al.*, 2000). Initially, the leaves were adapted to dark for 30 minutes and, after this period, leaf tissues were exposed to a modulated red light (0.03-µmol m^{-2} s^{-1}) and the initial fluorescence (F_0) was determined. Then, a pulse of 0.8 s of saturating actinic light (> 6000 µmol m^{-2} s^{-1}) was applied

and the maximal fluorescence (Fm) was determined. With these results, the potential quantum yield of the photosystem II was estimated, using the equation Fv/Fm = (Fm - F$_0$) / Fm.

The effective quantum yield of photosystem II was determined by superimposing a saturation pulse on leaves previously adapted to environmental light, and calculated as ΔF/Fm¹ = (Fm¹ - F)/Fm¹, where F is the maximum fluorescence yield during the saturation pulse (Genty *at al.*, 1989). The ΔF/Fm¹ was used to estimate the apparent electron transport rate (ETR) by using the equation ETR = ΔF/Fm¹ x PFD x 0.5 x 0.84, where PFD is the photon flux density (µmol m^{-2} s^{-1}) incident on the leaf; 0.5 is the value corresponding to the fraction of excitation energy distributed to the FSII and 0.84 is the value corresponding to the fraction of incident light absorbed by the leaves.

The non-photochemical quenching coefficient of Stern-Volmer was calculated as NPQ = (Fm-Fm')/Fm' (Bilger & Björkman, 1990). As described for gas exchange, the evaluations with portable fluorometer were performed between 08h30 min and 10h30 min, always in the same area of each leaf being evaluated.

The data relating to the physiological variables were submitted to descriptive analysis, followed by the standard error of the mean.

RESULTS AND DISCUSSION

The data obtained for plant height and root volume height and root volume (Figure 1A and B) and those of dry matter accumulation in plant parts (Figures 2A, B, C, D) over the cycle of *S. arundinaceum*, were adjusted to a logistic model of the type Y = a/[1 + exp - (x − b / c)], where Y is the dependent variable in question and X is the independent variable (time), and *a*, *b* and *c* are the estimated parameters of the equation.

In the model estimated for the height of *S. arundinaceum*, it is observed that the weed stands out for its size, reaching 1.91 meters at 113 DAT (Figure 1A). The height of plants is an important feature and can influence the competition relations between plants, depending on the neighboring species, their growth behaviors and coexistence period (Zanine & Santos, 2004). The coexistence of *S. arundinaceum* with smaller crops, such as soybeans (Rezende *at al.*, 2012), beans (Tavares *at al.*, 2013) and corn (Silva *at al.*, 2004), helps to reduce penetration of light in the canopy of these crops, resulting in greater production losses.

Similarly to the plant height, *S. arundinaceum* has significant root production, measured by the root volume (Figure 1B), indicating the extent of the root system of this species. Deep roots allow plants to access available

water sources after upper soil layers dry, adapting its growth to low rainfall seasons, often becoming more competitive plants (Grieu *at al.*, 2001).

Considering the total dry matter production of *S. arundinaceum* (Figure 2D), the plants showed slow initial growth up to 57 DAT and, thereafter, up to 113 DAT, showed fast and constant dry matter accumulation even

with foliar senescence (Figure 2B) and stabilization of the stem growth (Figure 2C). This behavior is due to the accumulation of root dry matter (Figure 2A), which represented the largest fraction of dry matter accumulated by the plant.

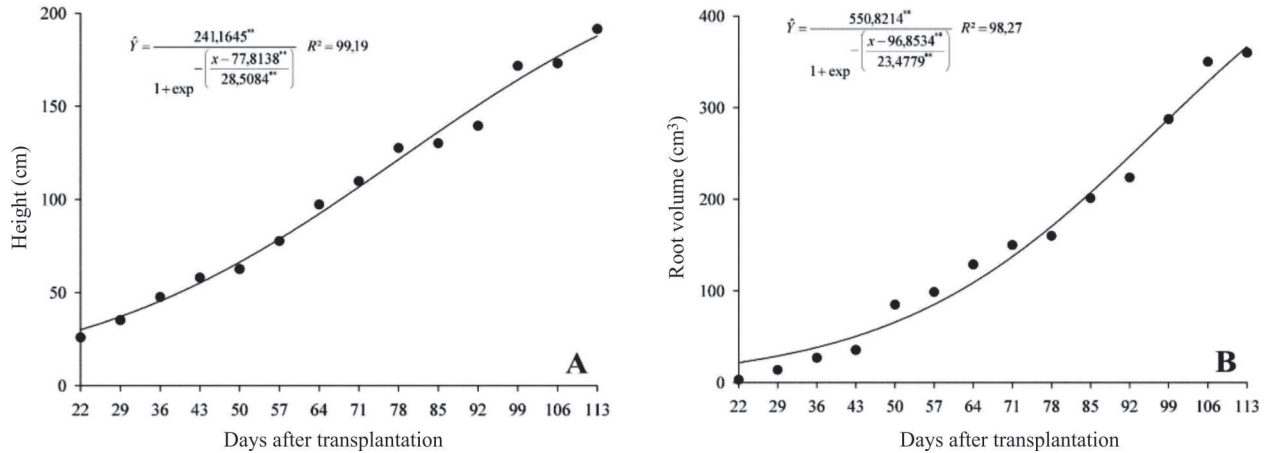Nevertheless, the final dry mass obtained demonstrates the high ability of this species to

Figure 1: A- Height (cm), B- Root volume (cm^3) of *S. arundinaceum* along its development cycle.
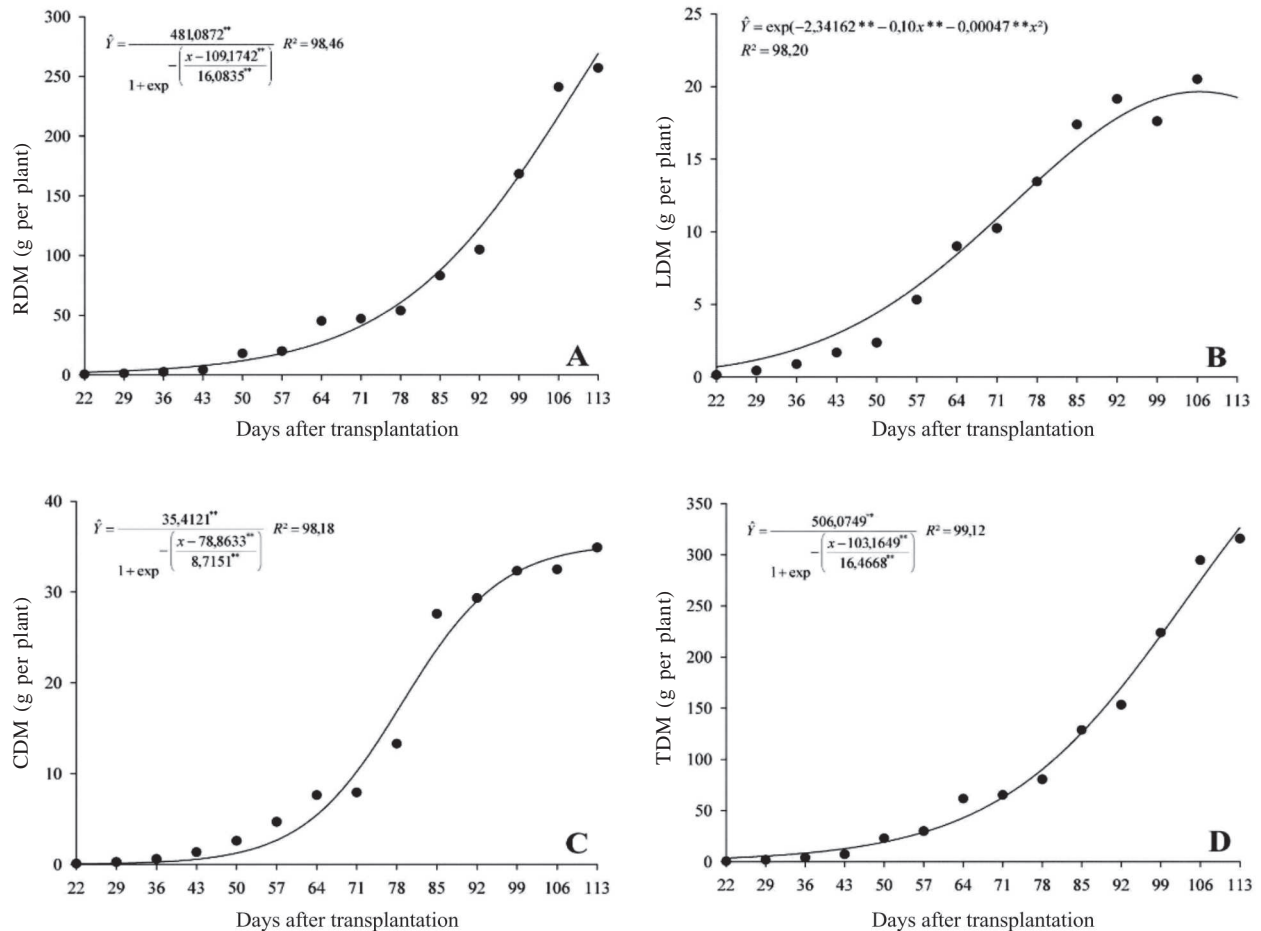

Figure 2: Dry matter accumulation of *Sorghum arundinaceum* along its development cycle: A - Root Dry Matter (RDM); B - Leaf Dry Matter (LDM); C - Stems Dry Matter (SDM); and D - Total Dry Matter (TDM).

accumulate mass, especially at the end of its cycle, presenting at 113DAT, mean values of 315.77 g per plant, and production of approximately 257.03 and 58.74 g for roots and shoots, respectively. The maximum dry matter produced by *S. arundinaceum* was higher than in experiments with grass weeds *Digitaria insularis* (Machado *at al.*, 2006), *Chloris polydactyla* (L.) Fedde (Carvalho *at al.*, 2005b), *Brachiaria decumbens* Stapf (Bianco *at al.* 2005) and dicotyledonous weeds *Siegesbeckia orientalis* L. (Aguilera *at al.*, 2004), and *Richardia brasiliensis* gomes (Pedrinho Jr. *at al.*, 2004). This higher dry matter accumulation, when compared with the other species, occurred mainly by the growth habit of the plant and the C_4 metabolism, that was favored by the experimental conditions of temperature and light. Silva & Silva (2007) state that the C_4 photosynthetic metabolism confer several attributes beneficial to plants, especially in hot and sunny environments, with high photosynthetic rate, low CO_2 compensation point and low photorespiration rate.

For leaf dry matter, there was a more intense increase from 50 DAT, reaching the maximum accumulation after flowering, 92 DAT, showing a declining trend from 99 DAT (Figure 2B). For the stems, the stability of dry matter accumulation occurred at the end of the evaluation period, 113 DAT.

Considering the weed dry matter partitioning throughout the growth cycle, the roots present an accumulation index superior than 60% of total dry matter in relation to the other parts of the plant (Figure 3), indicating significant photoassimilate allocation in the root system. Bianco *at al.* (2004) found in the photosynthate partition of *Rottboellia exaltata* (Jacq.) Fél. that the roots at 21 DAT contributed approximately with 60% of total dry matter, but this partition was reduced with the extension of the plant cycle, reaching 40%, on average, at the end of the experiment at 133 DAT. Similar behavior was observed for *Digitaria insularis* (MACHADO *at al.*, 2006) and *Brachiaria decumbens* (BIANCO *at al.*, 2005). This differentiated partition for *S. arundinaceum*, favoring the root system, is an important survival strategy in adverse conditions for the recruitment of resources in the soil environment.

Concerning the shoot, up to 43 DAT there was a higher average attendance of leaves in relation to the stems, from 23 to 17%, respectively; however, after flowering (at 92 DAT), the leaves, main organs in the production of assimilates, reduced their participation, leading to an increased allocation to the reproductive structures and roots (Figure 3). Panicle and seed dry matters showed small average increases of 7.9 and 2.3%, respectively, of the total dry matter, at 113DAT.

The leaf area of *S. arundinaceum* showed slow growth up to 36 DAT and then, a rapid increase, reaching peak at 87 DAT with 876.89 cm^2; from that date until the end of the test, it showed a decrease due to leaf senescence and the formation of reproductive structures (Figure 4A). It was observed for this species that, despite the size and the high dry matter accumulation, the maximum leaf area obtained was lower than in other species of C_4 metabolism such as itchgrass (Carvalho *at al.*, 2005a and b) and corn (Sangoi *at al.*, 2007).

The higher RGRs occurred in the early growth up to 43 DAT, reaching an average value of 0.082 g g^{-1} day^{-1} (Figure 4B). Regarding other weed species, these values were higher than those found by Machado *at al.* (2006) for *Digitaria insularis* (0.072 g g^{-1}day^{-1}). According to Benincasa (2003), with the increasing dry matter accumulated by plants, the need for assimilates to maintain the already formed structures increases, making the amount of photosynthate available for growth to be lower and the RGR to decrease over time.
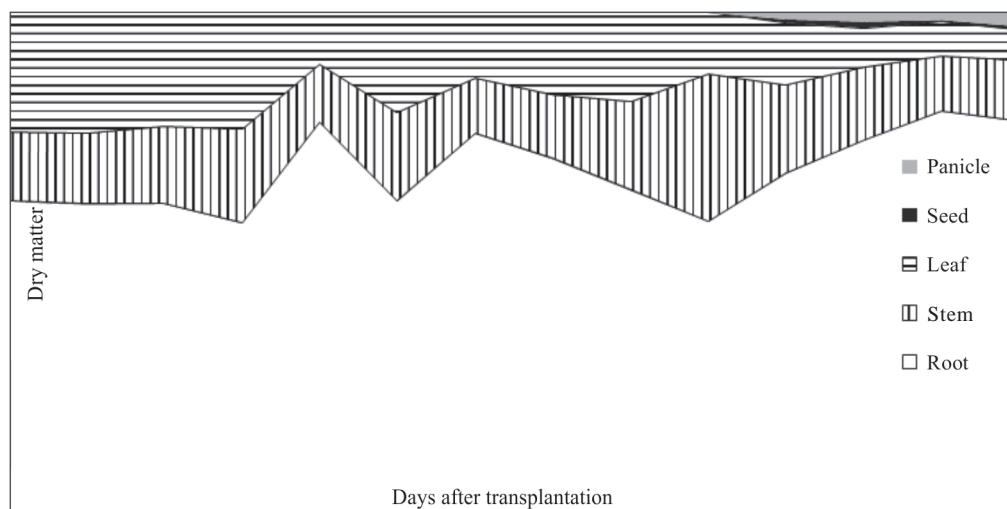

Figure 3: Percentage distribution of dry matter in different parts of *Sorghum arundinaceum* throughout their growth cycle.

Specific leaf area (SLA) relates leaf area and leaf mass. *S. arundinaceum* showed higher values at 22 DAT, with 223.90 cm^2 g^{-1}, and decreasing values until the end of the experiment, with 32.21 cm^2 g^{-1} (Figure 4C). Similar decreasing behavior along the *S. arundinaceum* cycle was observed for leaf weight ratio (LWR) (Figure 4D), which represents how much the plant invested of its production by photosynthesis for the leaves, showing reduction of the useful photosynthetic area and the lower participation of leaves in the total dry matter. Similar results were observed in weeds and crops (Machado *at al.*, 2006).

In general, it was observed for this species that, despite the high height, its initial growth is slow, with high dry matter production at the end of the cycle and a high capacity to allocate assimilates in the roots.

For the results of gas exchange related to photosynthetic rate (*A*), there was no variation in all phenological stages evaluated in the weed. However, the values were close to those found by Gonçalves *at al.* (2010), for sugarcane (24 μmol CO_2 m^{-2} s^{-1}), and Carvalho *at al.* (2009) for corn (24 μmol CO_2 m^{-2} s^{-1}),

which are plants of C_4 metabolism. In C_4 plants, the higher net photosynthesis rates are due to the ability to concentrate CO_2 at the site of rubisco, which reduces losses in the photorespiratory process that is high in C_3 plants (Taiz & Zeiger, 2013). In work by Ferreira *at al.* (2011), evaluating the photosynthetic activity of soybean, at the flowering period, and the weeds *Brachiara decumbens* and *Bidens pilosa* L., both of C_4 metabolism during the growing season, they noted that the weeds showed similar photosynthetic activities, between 10.5 and 11 μmol CO_2 m^{-2} s^{-1}. The activities were different from those of soybeans, which showed photosynthetic rate around 9.4 μmol CO_2 m^{-2} s^{-1}. However, they all have lower values than those of *S. arundinaceum*, which showed results ranging from 20.33 to 21.87 μmol CO_2 m^{-2} s^{-1} (Figure 5A).

For transpiration rate (*E*), different behaviors were found among the phenological phases of the weed *S. arundinaceum*. At the vegetative growth phase, the *E* value was 2.69 mmol m^{-2} s^{-1}, while at the flowering and maturation, it was 1.62 and 4.23 mmol m^{-2} s^{-1}, respectively (Figure 5B). Gonçalves *at al.* (2010) observed an *E* value
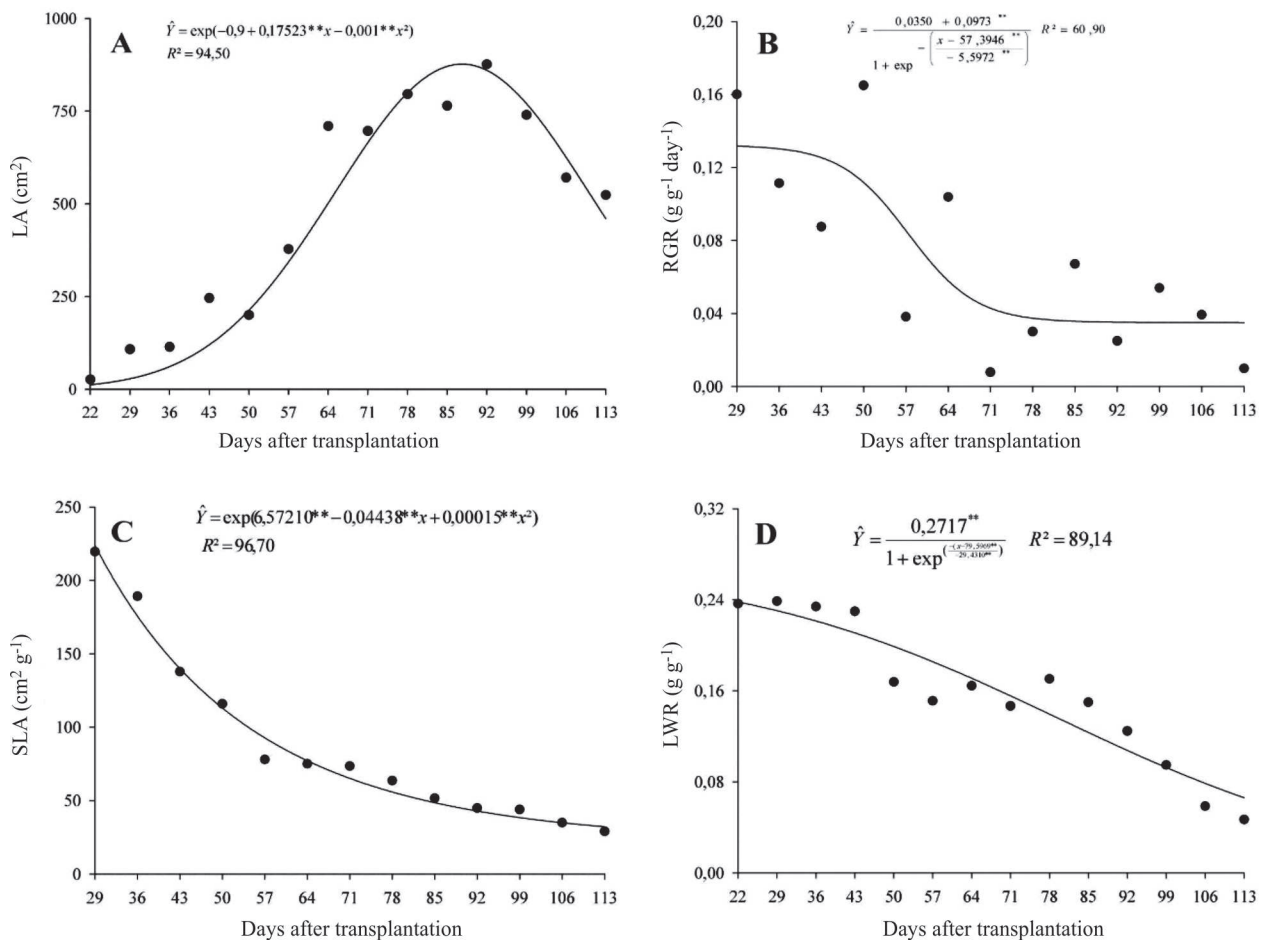

Figure 4: A- Leaf area (LA); B- Relative Growth Rate (RGR); C- Specific Leaf Area (SLA); and D- Leaf weight ratio (LWR) of *Sorghum arundinaceum* along its development cycle.

of 4.5 mmol m^{-2} s^{-1} with sugarcane, similar to that observed for *S. arundinaceum* at the maturation phase, 4.23 mmol m^{-2} s^{-1}.

A similar behavior was observed for the stomatal conductance (*gs*), in the different phenological phases of *S. arundinaceum* (Figure 5C), which also are similar to findings in the literature for sugarcane (Gonçalves *at al.*, 2010) and corn (Magalhães *at al.*, 2009). The conductance is proportional to the number and size of stomata and their opening diameter, which depend on factors inherent to the genotype and the environment (Brodribb & Holbrook, 2003). In the evaluations, the ratios *Ci/Ca* of *S. arundinaceum* did not vary significantly over the days of evaluation (Figure 5D), oscillating between 0.333 and 0.377.

The measurement of chlorophyll fluorescence is the technique used to investigate the photosynthetic capacity of the plant. According to Bolhàr-Nordenkampf *at al.* (1989), the yield of chlorophyll *a* fluorescence reveals the level of energy excitation in the pigment system that drives photosynthesis, and provides subsidies to estimate the inhibition or damage in the electron transfer process of the photosystem II and, when the plant has its

photosynthetic apparatus intact, the Fv/Fm ratio varies between 0.75 and 0.85.

For *S. arundinaceum*, the mean values in all phenological phases were similar and remained at 0.79 (Figure 6A), indicating that there was no photoinhibitory damage in the PS II reaction centers.

For the effective quantum yield of FS II (ΔF/Fm') and ETR there was a similar behavior, manifested by an increase of these variables in the flowering of *S. arundinaceum*, in relation to the other phenological stages (Figure 6B and 6C). According to Lu *at al.* (2003), the reduction of the ΔF/Fm' values is reflected in the reduction of the capture efficiency of excitation energy by the FS II reaction centers, corroborating the observations of lower ETR values found at vegetative growth and at the maturation phase of *S. arundinaceum*. As for the NPQ, at maturation, values higher than those in the other phenological phases were found (Figure 6D), indicating that the plants are dissipating more energy in heat form (Figure 5B). This behavior, at the maturation phase of *S. arundinaceum*, may be associated with leaf senescence, related to leaf yellowing and the loss of chlorophyll (Falqueto *at al.*, 2009).
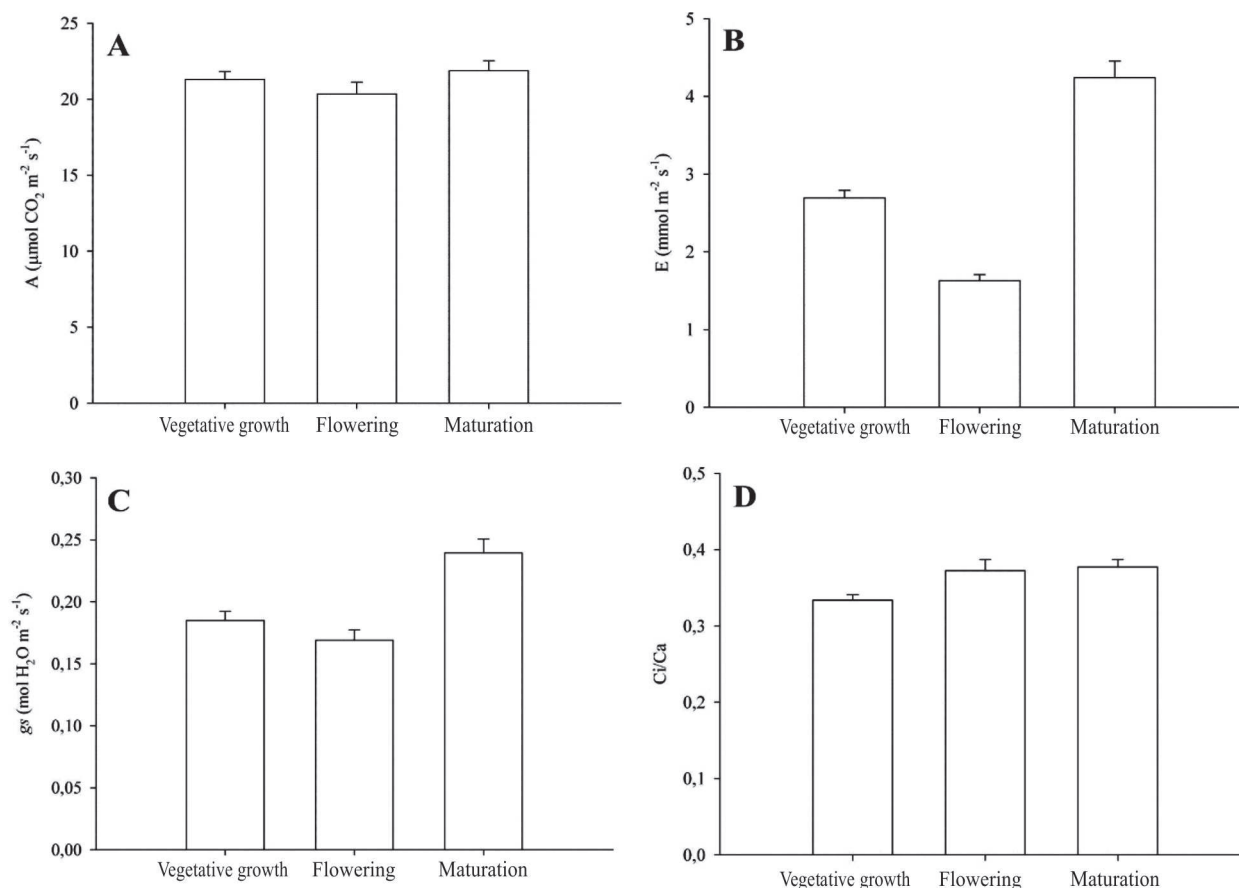

Figure 5: A- photosynthetic rate (*A*); B- transpiration rate (*E*); C- Stomatal conductance (*gs*); and D- ratio *Ci/Ca* in *Sorghum arundinaceum* plants at the vegetative growth, flowering and maturation.
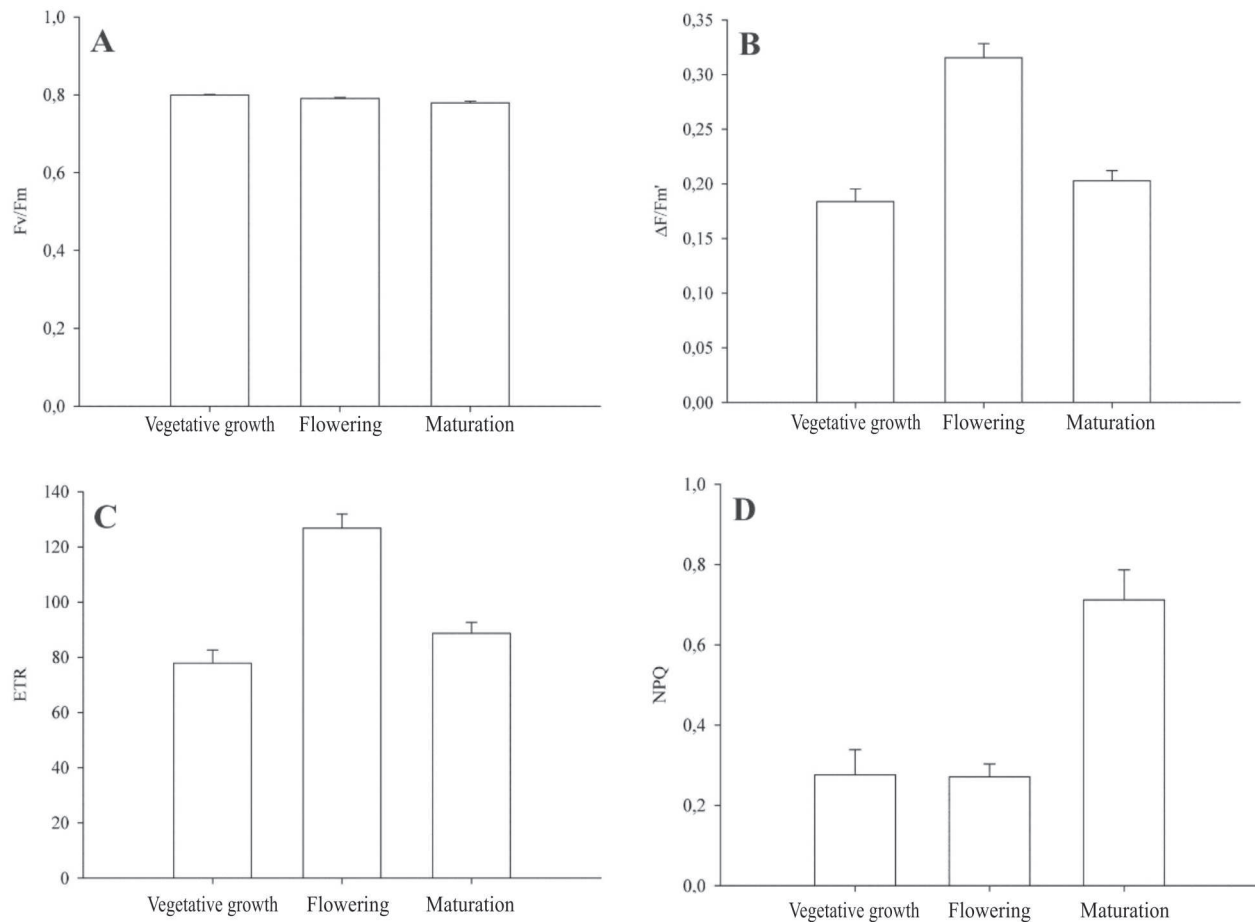
Figure 6: A- Maximum quantum yield of FS II (Fv/Fm); B- Effective quantum yield of FS II (ÄF/Fm'); C- Electron transport rate (ETR); and D- Non-photochemical quenching coefficient (NPQ) in *Sorghum arundinaceum* plants at the vegetative growth, flowering and maturity.

CONCLUSIONS

S. arundinaceum show high size, slow initial growth, but high dry matter production at the end of cycle. Most of the dry matter is allocated in the roots. It has values of specific leaf area, relative growth rate and leaf weight ratio similar to other C_4 grasses.

The photosynthetic rate and maximum quantum yield of FS II of *Sorghum arundinaceum* are similar throughout the plant cycle. It presents effective quantum yield of FS II and higher value of electron transport rate in the flowering period. At maturation, S. *arundinaceum* showed higher values of transpiration rate, stomatal conductance and non-photochemical quenching coefficient.

Considering that *S. arundinaceum* has physiological and growth characteristics similar to other invasive grasses of C_4 metabolism, the management of this species requires specific care, especially in spring-summer crops and in the early stages of their establishment.

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